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REVIEW ARTICLE

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Effects of ethnicity on skeletal maturation: consequences for forensic age estimations

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Abstract An X-ray of the hand is an important method in forensic science for estimation of the age of juvenile suspects with uncertain date of birth. Relevant X-ray standards for evaluation of skeletal maturity are available for white US Americans as well as for North and Central Europeans. The applicability of these standards to members of ethnic groups different from the reference population has been the subject of controversial discussion. More than 80 publications were analysed with the view to finding out whether skeletal maturation is affected by ethnic identity. It was concluded that skeletal maturation takes place in phases which are identically defined for all ethnic groups. Time-related differences in passing those stages of skeletal maturation within the relevant age group appear to be unaffected by ethnic identity. It is the socio-economic status of a given population which is of decisive importance to the rate of ossification. The application of X-ray standards to individuals of a socio-economic status lower than that of the reference population usually leads to underestimation of that person's age. In terms of criminal responsibility, this is of no adverse effect on the person concerned.

Key words Age estimation · Skeletal maturation · Ethnicity

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Introduction

Forensic scientists are regularly asked for expert opinions on age to determine the age of criminal liability or applicability of adult penal law to suspects of uncertain date of birth.

Age estimation of suspects has been on the agenda of the Institute of Legal Medicine of the Berlin University Hospital Charité since 1992. The growing importance of forensic age assessment is underlined by a rapid rise in the number of expert reports. The annual number of age assessments conducted at the Berlin-based Charité Institute of Legal Medicine can be seen in Fig. 1. The trend of annually growing numbers of age assessment procedures for the period from 1995 to 1998 fully applies to the German language region, as documented in a recently conducted survey (unpublished results).

Formal court ruling provided, age is estimated by a physical inspection by a forensic pathologist in combination with an X-ray of the left hand by a radiologist as well as dental assessment by a forensically experienced dentist, including dental status and evaluation of an orthopantomogram.

Romania, Vietnam, Lebanon, Bangladesh and Turkey have so far been the most common countries of origin of probands investigated in Berlin (Fig. 2). Other countries were Bosnia-Herzegovina, Egypt, Ethiopia, India, Iraq, Moldavia, Mongolia, Nigeria, Pakistan, Palestine, Poland, Sierra Leone, Syria and Yugoslavia. However, white US Americans as well as north and central Europeans, are the reference populations for the X-ray maps available for age assessment [25, 50, 55, 57]. The applicability of these X-ray standards to members of other ethnic groups has been questioned not only by the legal profession but the effects of ethnicity on skeletal maturation have also been controversially discussed in the medical community. This was the background against which an evaluation was undertaken of worldwide published studies into bone maturation of various ethnic groups.

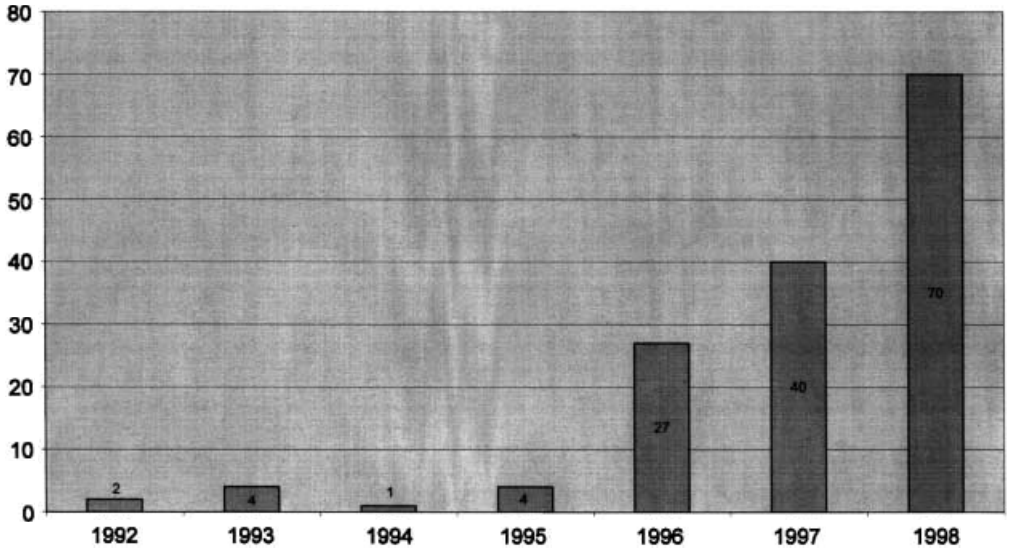

Fig. 1 Annual number of age estimations carried out at the Institute of Legal Medicine Berlin (Charité)

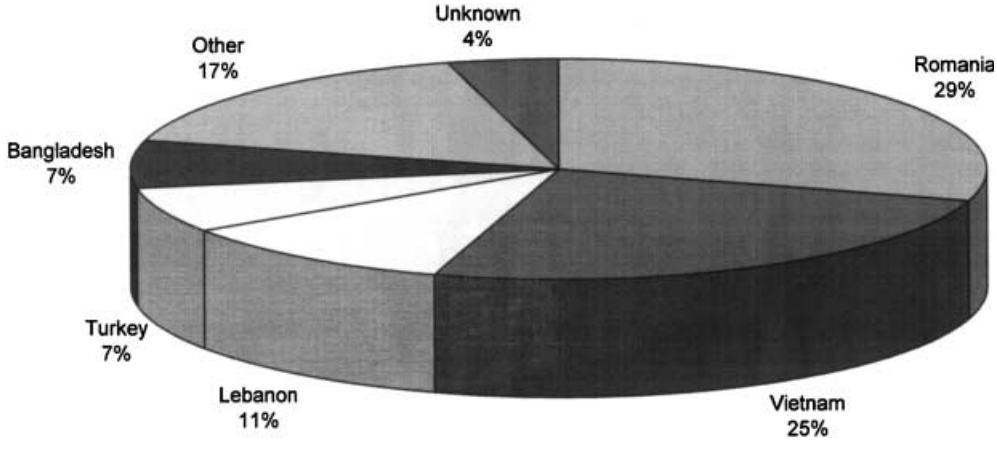

Fig. 2 Distribution of the probands investigated with respect to the country of origin

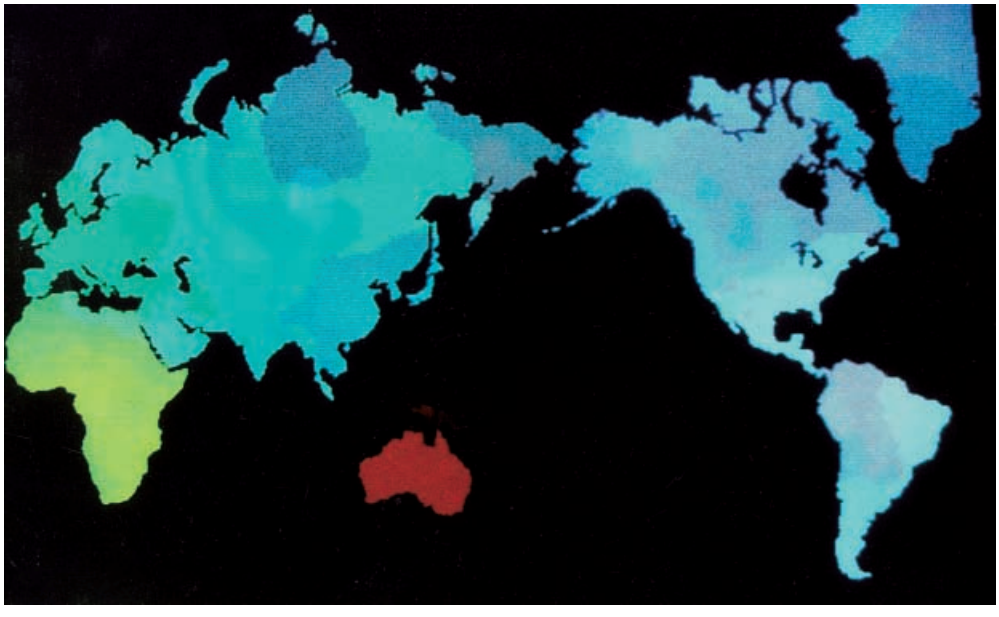

Fig. 3 Geographic distribution of the major ethnic groups of the world population prior to the modern migratory movements in the early 1500s [13]. Different colours were used for marking: *yellow* for Africans, *red* for Australians and *green* for Europids. The largest variation was recorded from Mongoloids, symbolised by *light brown to green* in Central Siberia to *violet* in America

Ethnic groups

The term "ethnicity" is used with different connotations. In the context of this publication, it is exclusively used to define genealogical relationships.

Cavalli-Sforza et al. [13] subdivided the world population into four major ethnic groups by typing more than 1,800 native populations with over 110 different genetic markers. These main groups are Africans, Australians, Europids (Caucasians) and Mongolids. The geographic distribution of the main groups prior to the modern migratory movements in the early 1500s, can be seen in Fig. 3. Conclusions from an individual's place of birth on the ethnic identity cannot be easily drawn for recent populations that are strongly affected by migratory movements.

Cavalli-Sforza's proposition, based on simple genetic markers, does not consider polygenic control and epigenetic effects on skeletal maturation, which, however, is irrelevant for the purpose of this study, since that proposition is merely aimed at providing a working basis for an ethnic subdivision of the world population by strictly genetic criteria.

Studies on skeletal maturation

The development of the hand skeleton (including the wrist) is considered to be representative of skeletal development as a whole [23, 25, 26, 52, 55, 56].

A multiplicity of publications on skeletal maturation in numerous populations were evaluated for the purpose of this study [e.g. 1, 4, 10–12, 19, 24, 25, 28, 29, 34, 36, 39, 44, 45, 48, 49, 54, 55, 57–59].*

Three methods are available for assessment of hand skeleton maturity:

1. The atlas method is an approach by which the radiograph of a hand is checked by defined criteria against X-ray standards, which are characteristic of each age level [25, 31, 50, 52, 57], to determine the skeletal age of the individual concerned.
2. With the bone-by-bone method, a specific bone age [25] or maturity level [55] is assigned to each bone (or selected bones) to derive the average age of all bones examined.
3. The third method is usually applied when several skeletal regions are to be investigated at one time. Skeletal age is determined by means of ossification tables which show periods for the emergence of ossification centres and synostoses [17, 25, 43, 51].

Studies are available on skeletal maturation of Europids [25, 28, 55, 57], Mongolids [10, 14, 19, 29, 54], Africans [6, 36, 39, 58] and Australian Aborigines [1, 11], i.e. for representatives of all major ethnic groups. The most informative studies into ethnicity, age groups and case numbers are presented in Table 1.

*A full list of evaluated publications may be obtained from the authors

The atlas method according to Greulich and Pyle [25] is the most common method for determination of skeletal maturity [15, 40]. The first edition of the *Radiographic atlas of skeletal development of the hand and wrist* was published in 1950, the second in 1959 and the most recent reprint in 1988. Greulich and Pyle established their X-ray standards on the basis of hand radiographs from the Brush Foundation Longitudinal Study. In that study, research workers had examined 1,000 US Americans of north European descent, aged between 0 and 18 years and living in Cleveland, Ohio, over a period from 1931 through 1942. The most representative of 100 radiographs was chosen for each age level.

Numerous populations have been investigated using the X-ray standards developed by Greulich and Pyle and evidence was found to the effect that all test populations underwent defined stages of hand skeleton maturation in one and the same sequence, although certain stages were quite often reached later when compared with the children who had been examined by Greulich and Pyle [14, 42, 54, 57, 58] (cf. Table 1).

What are the causes underlying comparatively retarded ossification rates of numerous populations?

Several authors have stressed the high socio-economic status of the children examined by Greulich and Pyle [4, 24, 57], although ethnic, regional and climatic differences as well as the probands state of health are discussed as possible causes of retarded skeletal maturation. There are several potential factors of influence and their simultaneous action makes assessment of retardation difficult especially as the validity of some of those investigations seems to be limited due to low numbers of cases, the exclusive consideration of non-relevant age groups and because of lack of information on health, ethnic identity and socio-economic status and absence of confirmed data on proband age. Hence, for the problem at hand, the greatest relevance may be claimed for studies on various ethnic groups of similar socio-economic status and living in one and the same region or populations of one and the same socio-economic status living in different regions. Such studies are available from the USA where research has been conducted on Europid, Mongolid and African populations [e.g. 24, 25, 28, 34, 45, 48, 49] as well as from numerous ethnic groups of the former Soviet Union [e.g. 3, 5, 12, 41, 44, 46, 53].

In a comparison with the Greulich-Pyle standards, racial differences were discussed by Sutow [54] as one of the causes of retarded skeletal maturation of Japanese children living in Japan (cf. Table 1). His findings were checked by Greulich [24] who referred to Japanese individuals living in the USA. He studied hand bone development in 898 children of Japanese descent aged between 5 and 18 years and living in San Francisco Bay, California. While retarded skeletal maturation, in comparison with the Greulich-Pyle standards, had been recorded by Sutow from all age groups of Japanese living in their own coun-

Table 1 Selected comparative studies of skeletal maturation

Authors	Reference	Populations studied	Number of probands	Age group (years)	Method	Reference population	Results
Abbie & Adey	[1]	Australian Aborigines	58	0–19	Ossification tables	Europeans	Within European range of scatter
Brown & Grave	[11]	Australian Aborigines	123	5–20	Atlas method	US Americans of North European descent	Boys retarded by up to 10 months, girls by up to 6 months
Greulich	[24]	US-based Japanese	898	5–18	Atlas method	US Americans of North European descent	High similarity
Johnston	[28]	White US Americans in Philadelphia	120	7–17	Atlas method	US Americans of North European descent	Accelerated by up to 0.65 years, depending on age
Mackay	[36]	East African Blacks	1360	0–18	Ossification tables	Chicago-based US Americans	Retardation by 1–1.5 years
Newman & Collazos	[42]	Peruvian natives	> 200	10–15	Atlas method	US Americans of North European descent	Average retardation by 2 years and 9 months
Pashkova & Tsandekov	[44]	A: Natives of Kamchatka B: Russians in Kamchatka	A: 351 B: 368	11–19	Ossification tables		No significant differences
Roche et al.	[49]	Representative cross of the US population	6768	12–17	Bone by bone method	US Americans of North European descent	Comparative retardation, no consistent white-Negro differences
Sutow	[54]	Japan-based Japanese	2370	6–19	Atlas method	US Americans of North European descent	Retarded by 6–24 months, depending on age
Thiemann & Nitz	[57]	East Germans	5200	0–18	Atlas method	US Americans of North European descent	Contemporaneous emergence of ossification centres or up to 1.5 years later

try, such retardation was detected by Greulich only in boys aged between 5 and 7 years. Boys aged between 13 and 17 and girls between 10 and 17 even exhibited comparative acceleration. Greulich concluded that the significant retardation, in comparison with the Greulich-Pyle standards, which had been recorded from children living in Japan was attributable to less favourable nutritional and environmental conditions rather than to racial differences.

Improvement of living standards in recent decades has resulted in accelerated skeletal maturation even in Japanese living in Japan [29, 30] which, in the meantime has come to lie within the scatter of socio-economically advanced Europid populations [7, 59].

Hand skeleton development of a population of West African children aged between 10 days and 15 years was investigated by Massé and Hunt [39]. In comparison to children studied by Greulich and Pyle, they found early maturity in the early postnatal months, followed by deceleration and sometimes retardation in middle and advanced childhood. Marshall et al. [37] and Garn et al. [22] also reported comparatively accelerated skeletal development in Africans during their early years of age. On the other hand, there have been several studies which reported that in advanced childhood and adolescence no time difference in skeletal maturation existed between Whites and Blacks.

Platt [45] studied skeletal maturation in 100 black inhabitants of Florida, 143 Blacks in Philadelphia and 100 Whites in Philadelphia aged between 5 and 14 years. In none of these three groups was skeletal age, as determined by comparison with X-ray standards, significantly different from the chronological age. Platt compared his results with studies on black residents of Africa. Retardation by 1.5–2 years had been recorded by Mackay [36] from East Africans, while an average retardation of 16 months had been recorded from West Africans by Weiner and Thambipillai [58]. The assumption of an ethnic impact on skeletal maturation would justify expectation of a continuous series of phenomena ranging from severe retardation in Blacks in Africa to moderate retardation in Black US Americans who had mixed with Whites to absence of retardation in Whites. Such continuous series do not exist and Platt consequently postulated health and nutrition as the major factors of influence on skeletal maturation.

Skeletal maturation in 461 Black and 380 White US Americans in the Lake Erie region was studied by Loder et al. [34] between 1986 and 1990. Using the atlas method of Greulich and Pyle on the age group of 13–18 years, they recorded comparative acceleration of 0.45 years for white boys, 0.16 years for white girls, 0.38 years for black boys and 0.52 years for black girls. Johnston [28] studied

the same age group of white US Americans in Philadelphia by the same method and found acceleration values of 0.39 years for boys and 0.58 years for girls. Johnston's data for white US Americans were almost identical with Loder's findings from black US Americans, which seems to clearly underline that in the populations of the age group studied there were no ethnic differences with regard to skeletal maturation.

Roche et al. [48, 49] investigated skeletal maturation in the context of race, geographic region, family income and educational standards of parents in a representative cross-section of the US population in the age group between 6 and 17 years. They found no consistent Black-White differences, no significant differences among regions and no urban-rural differences.

Comprehensive studies were conducted on skeletal maturation in different ethnic groups of the former Soviet Union and 16 studies into 17 ethnic groups in different climatic and geographic zones of the former Soviet Union were evaluated by Pashkova and Burov [43]. Included were Russians, Ukrainians, Georgians, Armenians, Azerbaidjanis, Balkarians, Cabardines, Kazakhs, Tadchiks, Uzbeks, Ingushi, Chechenians, Udmurtians, Chukchen, Koryaks, Intelmenians and Evenkians. The range of variation at all stages of skeletal maturation was below one year in all populations studied. However, the causes of those variations were attributed by the authors to relatively low numbers of cases, different methods and techniques used in the studies or undiagnosed diseases of probands but were not attributed to ethnic, regional or climatic differences.

Studies so far evaluated seem to suggest that there is a genetically determined potential of skeletal maturation which does not depend on ethnicity and is available for exploitation under optimum environmental conditions (i.e. high socio-economic status), whereas a less favourable environment may lead to retardation of skeletal maturation. This assumption appears to be supported by studies on the relationship between socio-economic status, skeletal maturation and standstill of a secular trend of skeletal maturation in societies of highly advanced socio-economic standards [8, 9, 35, 47]. Also, there are several studies on the retarding effects which malnutrition and poor hygienic conditions along with rising morbidity may have on skeletal maturation [2, 8, 18, 20, 21, 27, 32].

Bogin and Loucky [8] studied the effects of social, economic and political settings on the growth of US-born children of Maya immigrants and compared their results with data recorded from Mexicans as well as from Whites and Blacks in the US and Mayas in Guatemala. They found that Maya children born in the US were taller and heavier and carried more fat and muscle mass than Maya children living in a village in Guatemala. However they were on average shorter than children of Black, Mexican-American and White ethnicity. Children of Maya immigrants born in the United States tended to be taller than immigrant children born in Guatemala or Mexico. With reference to the plasticity theory and life history theory from biology [33, 38], they concluded that the body size of a child was a historical record of both the child and its parents. These findings were attributable to cross-generation effects of chronic malnutrition and morbidity. Body weight and body composition, however, were reflections of current events.

Further studies will be required to find out whether the ossification rate is a one-generation record or a cross-generation record.

Conclusions

The following conclusions may be drawn for forensic practice:

1. Studies are available on skeletal maturation in populations of all major ethnic groups. In all populations studied, skeletal maturation was found to take place in identical, defined stages.
2. Time-related differences in passing through these stages of skeletal maturation were obviously not affected by ethnicity in the relevant age group. Hence, as a matter of principle, X-ray standards for forensic age estimation may be applied to ethnic groups which differ from the reference population.
3. The rate of ossification is primarily affected by the socio-economic development of the population concerned. Application of X-ray standards to an accused person of a socio-economic status lower than that of the reference population usually leads to underestimation of that person's age. In terms of criminal responsibility, this has no adverse consequences for the person concerned.
4. That risk of underestimation of age should be underlined in any expert opinion to protect the person concerned from subsequent setback that may result from an estimation of too low age, for example with regard to pension claims.

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